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Applications of Radiation Physics in Medical Imaging and Treatment: a Cross-Disciplinary Approach

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Abstract: Radiation physics plays a crucial role in advancing medical imaging and therapeutic applications, yet gaps remain in optimizing its integration across disciplines. This study explores the intersection of radiation physics with medical imaging techniques such as X-ray, MRI, CT, and ultrasound, along with its applications in cancer treatment via radiation therapy. A literature-based analytical approach was employed to assess recent innovations and safety protocols in radiation-based medical interventions. Findings indicate that technological advancements, including AI-driven imaging analysis and precision-targeted radiation therapy, significantly enhance diagnostic accuracy and treatment efficacy. Results suggest that further interdisciplinary collaboration and regulatory frameworks are essential to balancing innovation with patient safety. The implications highlight the need for continuous improvements in radiation safety measures and integration of emerging technologies to optimize patient care.

Keywords: radiation physics, medical imaging, radiation therapy, X-ray, MRI, CT scan, AI in healthcare, patient safety.

1. Introduction to Radiation Physics and Medical Imaging

Medicine, a discipline that faces the study and treatment of diseases and injuries, embraces a multidisciplinary background, joining among other branches physics and engineering. By studying the behaviour and interaction of radiation with matter, a branch of physics, Radiation Physics is established. The relationship between the fundamentals of radiation physics and its applications in medical imaging and treatments is introduced. The state of this symbiosis can be found in medical imaging, where from the behaviour of radiation, methods for diagnosis and study of pathologies have been developed. Medicine is then also nourished from physics and engineering knowledge. The importance of being able to understand the behaviour of radiation to take profit of its advantages while mitigating the risks associated is emphasized [1]. In the 20th century, the development of radiological sciences allowed for early diagnosis of a plethora of pathologies. There have been several developments from the obtention of the simple X-ray image by transmission, such as computed tomography, allowing the study of a certain region through different projections, or nuclear medicine techniques, monitoring the accumulation of a specific radiotracer, which have affected not only patient diagnostic but also treatments and research. Also, with the view of developing increasingly beneficial techniques from the medical point of view, therapy has also benefited from radiological science and advances. The unwanted consequences, in an attempt to maximise the benefit from the techniques, are also under study. All these create a field of research that, although initiated in mid-20th century, is still providing innovations and new questions, promoting multidisciplinary research. On one hand, the development of accurate computational models requires a deep knowledge of the radiation-transport phenomena, from the fundamental interactions to the macroscopic description of the beams. It is inherently a physics problem. On the other, engineering solutions are being explored. Efforts to develop new support devices depend however on safety. Staying in the framework of the order of magnitude of doses found in diagnostic imaging procedures, the literature gives some correlations between increased mutation risk and received doses. Naturally, other effects, which do not find straightforward a direct treatment in the framework of particle physics, affect to the same amount the efforts for improvement and acquisition of knowledge, showing a more evident interdisciplinary characteristic. This background aims at the presentation of an overview, which could serve as a guide for deeper exploration of the different aspects mentioned. The need to offer a common language, or at least some definitions, together with a brief compilation of the clinical benefits derived from the use of radiation physics techniques in health sciences, motivates this presentation. [2][3][4]

1.1. Fundamentals of Radiation Physics

Ionising radiation is the passage of particles, mainly in the form of electromagnetic radiation, that have sufficient energy to cause other atoms to release loosely bound electrons, thereby breaking chemical bonds. Types of radiation include alpha, beta, gamma and x-ray radiation. Alpha particles are electrically charged and have the highest ionisation rate; beta particles are high-energy, fast-travelling electrons that are less ionising than alpha particles; gamma and X-ray radiation are electromagnetic waves that are very penetrating and have low ionisation rates.

The strength of radiation is measured in units called becquerels (radioactive decay events per second) or curies (1 Ci = 3.7 × 1010 Bq), and the accumulated dose within matter is measured in becquerels per kilogram (Bq/kg) or gray (1 Gy = 1 J/kg) [5].

Radiation passing through a material can be attenuated by materials placed in the path of the radiation, which may fully absorb the radiation if it is a high enough density of heavy enough composition to affect the radiation. The attenuation of a material is measured by the Victorian derived water and/or lung tissue equivalent thickness of material that results in the same attenuation as the material being measured, this value is known as the Hounsefield value of the material. The term half-life is the time required for the activity to reduce to half the starting activity, is a constant for a material and is characteristic of some material or isotope. As a number of half-lives of a material have passed since the deposition of the material or calculation of an event the activity accrued to the material from this event can be considered to be negligible. This term is used in body scanning technology to limit storage and data retrieval due to the large amount of data gained from a CT scan and is used in the rules surrounding when material is safe enough to remove in an event.

1.2. Basic Principles of Medical Imaging

Medical imaging is critical for the diagnosis, treatment, and follow-up of pathologies in many medical areas. In current clinical practice, medical imaging is in most cases the primary or the complementary diagnostic tool used. The interpretation of an image is still a result of an intense study, implying the knowledge of the human anatomy and an understanding of the pathology. In many cases, the decision of patient management relies exclusively on the images. The complexity of medical imaging lies in the fact that it is addressed to specialists who must recognize particular signs from a big amount of information assets. Most medical imaging techniques are based on the capture of radiation or waves either passing through the body or emitted from within. Depending on the radiation source, the imaging method and the image capture system different internal structures can be visualized. Medical imaging can be roughly divided into two categories: ionizing and non-ionizing radiation medical imaging. The first category typically includes X-ray and computed tomography, where the internal structure visualization is based on the varying attenuation of the body to the radiation. In these methods an X-ray source bombards the body and the subject X-ray detects the remaining radiation. The image formation can be done by recording the absorption of the radiation or by compiling a three-dimensional image from axial slices. Non-ionizing techniques include magnetic resonance imaging and ultrasound. Magnetic resonance imaging centers on the ability of the nuclear spins to absorb and emit radio-frequency energy in the presence of a strong external magnetic field. In a typical MRI scanner the subject is placed in a strong and uniform magnetic field. Excited by radio frequency coils the hydrogen nuclei precess generating radio frequency signal that can be detected by coils. The magnetic field strength and the pulse sequence determine the contrast and the weighting of the images. The three-dimensional image created is based on the relaxation times of the tissue properties and the location of the resonating nuclei. During the scanning process additional gradients can be applied in order to produce targeting slices. By choosing the repetition time and the echo time the relaxation times of a tissue type can be optimized resulting to an optimal contrast. It should be pointed out that MRI machines cannot see the bone and the air. Ultrasound imaging technique relies on the interaction of the ultrasound wavefront with the human body. This imaging technique can record the transmission, the reflection and the backscattering of the pressure waves and the spatial frequency of features the size of the wavelength want to differentiate the backscattering source. A typical ultrasound machine consists of a screen, a display, a probe and a computer. The RF signal penetrates the body and in the interface between different tissue kinds generates a reflection or a re-transmission of the signal. The processing of the transmitted or the reflected signal can result to an image formation. As the wave reaches the interface its attenuation can be locally altered as a function of the impedance mismatch and the angle of incidence between the wave and the interface. The receiving of the reflected pulse takes place with the modulation of an amplitude of the reflected signal. The Kerr's effect creates a new wave which can be used to interrogate a washout flow. After the undersampling of the compressible fluids the amplitude can be discarded and the signal can be used for vessel visualization. Magnetic resonance angiography is the angiography that takes place inside the Magnetic Resonance Imaging devices and relies on the changes of the blood flow within the arteries. Digital Subtraction Angiography is another angiography technique in which the image's background is subtracted from the signal of interest. [6][7][8]

2. Types of Medical Imaging Techniques

Medical imaging is the technique of creating visual representations of the internal body for clinical analysis. It is a crucial diagnostic and investigative tool in health care, allowing the visualization of tissues and organs. Over time, various imaging techniques have emerged, each involving different principles of operation, providing a distinct perspective on human health conditions. Traditionally, X-ray imaging was the only type of diagnostic imaging, involving the use of ionizing radiation. With advancements in technology, more imaging modalities have become available, including computed tomography (CT), magnetic resonance imaging (MRI), and ultrasound, all with their strengths and limitations. Nuclear medicine and cardiovascular imaging are specialized forms of medical imaging, providing additional insights. Conversely, emerging technologies are bringing new modalities, such as functional MRI (fMRI), positron emission tomography (PET), elastography, and photoacoustic imaging, expanding the scope of applications and research in medical imaging [9].

To optimize the choice of imaging technique for a given clinical application, this article provides a comprehensive categorization and examination of available imaging modalities. It broadly categorizes imaging techniques into two classes of ionizing and non-ionizing radiation, each of which includes specific imaging modalities. For each imaging technique, an imperative overview of the principle of operation and technical aspects is presented, followed by advantages and limitations to provide a comparative perspective. Finally, particular uses of imaging modalities in diagnosing diseases are discussed, providing insights into how the choice of imaging technique should be informed by patient needs and clinical objectives. [10][11][12]

2.1. X-ray Imaging

The diagnosis and treatment of different diseases have been facilitated by medical imaging modalities; medical imaging serves as a powerful diagnostic tool and helps monitor disease conditions. With the ever-increasing demand for medical imaging worldwide, the importance of medical imaging extends to the healthcare of billions of people. Medical imaging is a comprehensive, cross-disciplinary field and the continuous de-mystification of the intrinsic relationship between medical imaging modalities and human health creates a flourishing environment for the generation and dissemination of scientific knowledge [9].

X-ray is one of the earliest and most widely used medical imaging modalities and plays an irreplaceable role in the routine examinations, diagnosis and treatment of diseases. Medical imaging using X-rays is performed by generating an X-ray beam, which is projected through the tissue and detected by a phased array of elements integrated within the imaging system, producing a radiographic image. Image contrast is generated from the different attenuation coefficients of the various materials that the X-rays pass through along their path of traversal from the acquisition to the detector. This contrast driven image forms an X-ray image that can then be interpreted by the physician or radiologist. X-ray imaging with high-energy ionizing radiation is capable of imaging through the body, providing an effective modality for the visualization of bone structure and certain soft tissues. The rapid acquisition time is beneficial for reducing motion artifacts and avoiding the loss of spatial-temporal resolution. The widespread use of X-ray imaging in current clinical practice, from routine diagnostics to advanced imaging in interventional procedures, makes it an indispensible complement to other medical imaging modalities. Committed to safeguarding the health of the patients and medical staff, the radiation dose of X-ray diagnosis should be managed effectively through the implementation of relevant regulations, standards and timely on-the-job training for professional staff. The patient protection structures such as protective curtains, glasses and closed wall rooms can effectively prevent unnecessary radiation exposure. Since its inception, there has been a continuous evolution in X-ray technology, advancing rapidly owing to the combined effect of many fundamental and practical experiments. With the development of infrared digital imaging and image processing techniques, more emphasis has been given to the improvement of image quality and radiation selection. Digital radiographic technology makes it possible for the system to capture and process images digitally, disclosing its superiority in dose reduction, elimination of the consumption of film and generating images with greater resolution and superior quality. Along a similar vein, X-ray residual also appears to be a conventional fluoroscopic technique based on imaging plates or film cassettes. However, based on the underlying mechanism of radiation detection, a new generation of fluoroscopy techniques have emerged with the superior advantage of real-time image processing and display on computer monitors. Correspondingly, the image obtained from computed tomography is no longer limited to the projection plane but in-depth fine imaging that can be shown as volume data. Despite the potential high diagnostic value, X-ray images also book disadvantage in that the viewing and interpretation of the diagnostic image is not always easy. In view of the overlap of structures and abnormal density, a specific anomaly can masquerade as normal structures on the image. At the same time, it is difficult to guarantee a perfect image after the large number of post-processing techniques, which can amplify and distort the data to resemble an inaccurate representation of the acquired image. [13][14][15]

2.2. Computed Tomography (CT)

In 1972, the Nobel prize in Physiology or Medicine was awarded jointly to Hounsfield and Cormack for their development of the Computed Aided Tomography. The Nobel Assembly at the Karolinska Institute awarded the prize for the contributions of Hounsfield for the way how he conceived the problem and of Cormack for the development of the mathematical formalism for the computation of the image. The principles of the CT scanning are the integration of X-ray technology with computer processing for acquisition, storage and reconstruction of a series of two-dimensional projections to produce cross-sectional images. The advantages over conventional radiography or projectional radiography are the liberation of structure superimposition which makes the visualization of complex anatomical parts much easier and the fact that a CT scan provides axial images. Due to these characteristics CT has been central to the evolution of medical imaging technology. The original papers by Hounsfield and Cormack emphasized the complexities of the image reconstruction algorithms, which still are very important for good contrast-to-noise ratio images. Despite its advantages and the tremendous progress in the development of reconstruction algorithms and the enhancements of the image quality, the general use of the CT has not been fully exploited for good clinical results and is not performed with the same proficiency as the normal projectional radiograph. The stochastic nature of the X-ray attenuation, imaging conditions and patient size have a major effect on the imageSize, thus it is necessary to apply some safety and avoid the overuse of CT. The improvements on the CT technology, acquisition and reconstruction techniques, image-processing strategies and newer multidetector architectures have wide and exciting applications. The current CT based imaging technologies, i.e. CTA, CTC, CBCT, CTP are transforming the practice of medical imaging, radiation oncology, image-guided surgery and intervention, dentomaxillofacial surgery and diagnostic industrial engineering. However, there are some dilemmas such as the large datasets that can entail an overload of irrelevant information or the need for interpretive expertise . In a radiological department setting the responsibilities for the risks and the benefits of the procedure are shared among different figures, e.g. the referring clinician and the radiologist. However, there is evidence that the potential risks of unnecessarily high radiation doses are often underestimated by all the figures and hence not adequately considered. Due to these considerations, with the aim to improve CT-based applications, a comprehensive, in impressively interdisciplinary terms, approach to CT of the CNS is presented.

2.3. Magnetic Resonance Imaging (MRI)

Magnetic Resonance Imaging (MRI) is a non-ionizing imaging technique that uses powerful magnets and radiofrequency (RF) waves to create detailed images of the body's internal structures. MRI provides excellent soft tissue contrast and is therefore invaluable in neurological and oncological clinical scenarios, among others. In addition to anatomical images, MRI can also measure many functional and physiological parameters. fMRI, for example, measures the brain’s blood flow changes in response to neural activity, whereas diffusion tensor imaging measures the diffusion of water in tissues. MRI is well-suited to a large number of clinical examinations and procedures, but also to difficult research studies on living people. This chapter covers MRI’s technical principles and latest imaging sequences that are of interest in the research setting. Due to MRI's demanding measures, its basic safety issues are discussed, including a list of contraindications and implantable electronic medical device management. MRI, as a modality, keeps innovating with seminal studies and advances routinely published. However, many questions regarding the optimal equipment, scanning methods, and data processing remain open. Scan time, patient comfort, and post-processing complexity are issues discussed. However, despite these challenges, MRI’s impact on clinical diagnostic imaging has transformed the field.

M4aes of hydrogen atoms in magnetic fields are the foundation of MR imaging (MRI). As atomic nuclei with an odd number of protons, hydrogen atoms spin about their axes creating a net magnetic moment. When placed in an external magnetic field, the net magnetic moment aligns along it, but also precesses perpendicular to it. Releasing RF energy at the Larmor frequency, the spinning atoms absorb it, making the net magnetic moment precess at a larger angle. Ceasing the RF irradiation, the excited nuclei return to their original alignment, thus releasing the absorbed radiation. Due to the signal’s in-phase and out-of-phase nature, a series of MRI-specific scans capture the radio signal decays [16]. This information is later processed mathematically to recreate the initial cross-sectional viewpoint through a complex series of computer algorithms. Though straightforward in concept, MRI is capable of acquiring tissue-specific high-quality images since different tissues take varied time lengths to return to equilibrium states. Moreover, the relaxation times can be influenced by forming different tissue contrasts.

2.4. Ultrasound Imaging

Ultrasound is a versatile and widely used imaging technique that is based on sound wave propagation. It is a cross-disciplinary subject in medical physics, involving physics principles in wave generation and propagation. Sound waves can be generated either by an oscillator or a transducer when electrical signals are transmitted. The sound waves can then propagate through different mediums, particularly soft tissues in the human body. When the sound waves encounter different tissues, reflection, refraction, transmission, and backscattering can occur. In this way, pulse-echo ultrasound measures the return trip time gap between the transmitted and received sound waves after bouncing off of various tissues [17]. Echoes are then detected, processed, and transformed to acoustic and/or electrical signals to reconstruct images. Many factors affect the quality of ultrasound images, such as the frequencies of ultrasound transducer, the speeds of sound in soft tissues and medium, and the amplification of ultrasound receivers by time-gain compensation, etc. It is portable with relatively low cost, and real time imaging can be obtained. More clinical applications of ultrasound imaging are emerging, such as obstetrics for pregnancy diagnosis or monitoring, cardiology for heart disease, guidance for different interventional procedures, etc. Ultrasound imaging is particularly suitable for tissues that are water-rich since the large acoustic impedance mismatch between different tissues can induce stronger echoes. This is a major advantage for applications of soft tissue imaging.

Ultrasound can also help detect gas bubbles or air-stones in the human body, and the ability to detect structures of bones is very limited, as typically bones have high attenuation on sound waves. With the use of a suitable acoustic standoff pad consisting of ultrasound gel or water between the ultrasound transducer and skin, much better acoustic coupling can be achieved, facilitating the generation of ultrasound images. Ultrasound technique has seen significant developments over the past half century. Some examples include more advanced probe design such as phased array, curved array, and single crystal; the advancement to produce 3D or multi-planar ultrasound imaging; Doppler mode to monitor blood flow or heart valve function; and elastography to quantify tissue stiffness by the relative time delay between consecutive ultrasound echoes. Many clinical settings adopt ultrasound imaging, but the basic physics principles can be challenging to grasp. A thorough understanding may be required to adequately adjust and optimize ultrasound parameters for best imaging performance while minimizing the risk of bio-effects, exposure, and potential misdiagnoses. [18][19][20]

3. Radiation Therapy in Cancer Treatment

Despite advances in technology and increasing understanding of the disease, cancer continues to represent an enormous burden on the U.S. healthcare system [21]. In the United States alone, more than 1.7 million new cancer cases are diagnosed each year. By 2030, it is anticipated that these numbers will exceed 21 million annual diagnoses and 13 million cancer-related deaths. In the United States, cancer is the second leading cause of death, accounting for nearly one in every four deaths. Due to the high morbidity and mortality rates associated with cancer, a multidisciplinary approach is vital for comprehensive care.

Treatment planning in radiation oncology refers to the designation of treatment delivery volumes and respective treatment plan parameters [22]. To achieve the treatment recommendations for an individual patient and their oncologic disease, multiple parties work together. Typically, a board-certified radiation oncologist, a medical physicist, and a dosimetrist are responsible for creating and validating the constrained plan. This typically involves the use of external beam X-ray therapy, high-dose radiation therapy, and/or brachytherapy. In general, treatment planning is designed based on standards of care and appropriate tumor volumes. Ideally, the plan is individualized to each patient and involves nuances based on the type, location, and specific patient factors. At the forefront of the goal in creating a treatment plan, it is necessary that the defined treatment volumes will receive the prescribed dose, as geometry is considered. The primary objective is to maximize the delivery of ionizing radiation therapy to the tumor volume while sparing surrounding normal tissues to minimize the integral dose. Any dose outside specific volumes is considered subtherapeutic and therefore it is crucial to avoid under-dosing the target. The complex 3D conformal plan is generated in block form using a beam model of the radiation treatment equipment. Tradition radiation therapy techniques typically involve simple mega-voltage units that deliver a high dose of ionizing radiation in large fractions using multiple fields with non-opposing beams. The basis behind this paradoxical treatment regimen is due the varying cell cycle phase of the different cells found in solid organ tumors. Resistant cells are often found in normally-dividing tissues adjacent to a tumor, within hypoxic regions of the tumor, concerted defenses of the hyperfractionation approach are used.

3.1. External Beam Radiation Therapy

External Beam Radiation Therapy (EBRT) is one of the most common methods used as an oncology treatment. It involves the use of high energy beams that are externally directed towards the tumor. The beams damage the DNA of cancerous cells, inhibiting their ability to multiply, thereby inducing apoptosis. EBRT is based on the principle of irradiating the tumor with high doses of radiation, thus killing the cycling cells while normal tissue is concurrently allowed to recover. This approach inherently aims for a sharp dose gradient around the target, which has led to the development of meticulous planning and delivery methodologies. Currently, EBRT approaches strive to maximize the delivered dose to the target by using sophisticated multi-beam or non-isocentric treatment techniques, while simultaneously minimizing exposure to healthy tissues. The exposed normal tissues receive low doses of radiation, but the cumulative amount may exceed the tolerance of radiosensitive tissues, resulting in both acute and late morbidity conditions. The complex interplay of all those parameters necessitates the balanced consideration of every aspect during the planning process. There exists a plethora of different technologies that can be employed to deliver radiation to the patient. The most widespread implementation involves the use of linear accelerators – devices that accelerate electrons and then stop them abruptly in a dense material, producing high energy x-ray and sometimes electron beams [23]. The developments over recent years have allowed for the creation of image-guided radiation therapy (IGRT) devices, which can help visualizing and positioning the patient into a planned setup with high precision before the treatment delivery [24]. Other volumetric verification techniques include MRI, ultrasound imaging, 4D CT, and optical surface scanning techniques. In recent years, yet another frontier in radiation therapy has arisen, which involves delivery of radiation using particle beams instead of the conventional photons and electrons. Particle beams are characterized by an increased stopping power close to the Bragg peak, allowing for accurate dose deposition and reduced scattering dose. Therapy with protons is already an established curative method; however, the availability of the requisite facilities, in particular, cyclotron or intensive synchrotron facilities, is limited, both due to high overall production costs and the necessity of bulky equipment. This has led to the emergence of carbon ion therapy. Carbon beams offer a better dose distribution to the target due to their increased relative biological effectiveness compared to the proton beams and can also be employed for radio-resistant and hypoxic tumors. All treatments need to undergo a quality assurance process, regardless of the delivery technique or technology employed, and have to be carried out safely and efficiently. Last but not least, it should be emphasized that EBRT is always a single modality, and an aspect of cancer treatment in which a comprehensive approach is essential. Therapeutic decisions should arise from a collective effort by a multidisciplinary team encompassing various medical professionals, and treatments must be delivered adhering to established sequences in due time. It is of paramount importance for oncologists to construct an individual treatment plan based on mass and biological properties characteristic of the cancer in each case: histology, site, grade, stage, and genomic modifications.

3.2. Brachytherapy

Brachytherapy is a form of internal radiation therapy, also known as sealed source radiotherapy or endocurietherapy, where radioactive sources are placed close to or within tumors. The goal of Brachytherapy is to realize conformal radiation dose distributions in the tumor with the aim of sparing the surrounding healthy tissues. Brachytherapy achieves a high localized dose of radiation to the tumor at lower overall doses, and therefore higher biological effectiveness compared to external beam radiation. Due to rapid dose fall-off outside the implant region, this contributes to relative sparing of the surrounding organs at risk. There are several different types of Brachytherapy including permanent low-dose rate (LDR) and high-dose rate (HDR) techniques. Cancers treated with Brachytherapy range over a broad spectrum, and depend upon tumor type and the anatomical location of the disease. Common treatment sites for Brachytherapy include cervix, prostate, breast, skin, and brain.

Radioactive implants within the body render both the implants and patient highly radioactive and are regarded as ‘radioactive sources’. As such, stringent safety protocols and Federal and State Legislation control the acquisition, use, and disposal of radioactive materials. With current day sealed source implants of radionuclides, the risk to trained staff is low. Nevertheless, a firm understanding of radiation protection, and training in the use of the source is essential before handling these implants [25]. Radiographic imaging is fundamental in the planning and verification of Brachytherapy treatment. Imaging is used for pre-treatment planning: the organ geometry, the applicator implant geometry, the dose planning, and verification of the implant source localization. During source implantation, imaging equipment is used to confirm the location of the sources. Post-treatment images are also obtained to review the treatment delivery.

However, to exploit the benefits of this treatment modality, it is essential to effectively address the specific issues and challenges of the technique.

Brachytherapy is a powerful tool in the treatment of cancer, offering many advantages over external beam radiation therapy. Since it is a form of radiation therapy, there are many side effects from the treatment so it is necessary to weigh the potential cure against the side effects. Ongoing developments in treatment delivery aim to increase the precision of source placement and dose optimization. Many new approaches and technologies have already been incorporated, including Conformal Brachytherapy Treatment Planning, TPS, and image-guided Brachytherapy. Further developments in this field, such as strut-assisted Brachytherapy, are also set to improve the effectiveness of this cancer treatment [26].

4. Radiation Safety and Regulations in Medical Settings

Safety of patient and staff is crucial in the medical use of radiation. The professional team plays many roles in the 'medical radiation protection' of patients, co-workers and the public. The implementation of a radiation safety programme has a strong focus on minimizing the 'radiation dose'. Patient protection can be achieved by adopting 'low dose procedures'. The justification process for a 'radiological examination' requires demonstration that the examination results in a 'net benefit'. Medical radiation protection of patients includes undertaking all radiological and nuclear medicine procedures, notably radiologists and radiographers. Doses to patients in such a discipline are derived from a publication [27]. The optimization in the medical use of ionizing radiation is of fundamental importance and includes main techniques, using an iterative methodology in: tube voltage and automatic exposure control, selection of procedures, setting of standard imaging protocols, recommended investigation, and quality assurance of equipment. Another common field of protection in medicine is concerned with the aesthetic 'asymptotic patient' who might receive 'radiological examination'; instructions and advices concerning patient's dose are covered in some protection recommended sections of the European 'COCIR' BSS (Basic Safety Standard) 'Guide'. Protection of the embryo or due to the 'pregnant patients or nursing' procedure involving the uptake or administration of 'radio-active substance'. The main protective measures concerning exposure to patients are: restriction of exposure, optimization of 'radiodiagnostics', optimization of 'radiometerapeutic's', patient dose reference level, training in optimization, and age dependent diagnostic reference levels. Proper risk assessment should be undertaken for each procedure, and the patient must be provided with full and clear information on the ionizing radiation expected to be received and the potential for severe radiation induced deterministic damage.

5. Innovations and Future Directions in Radiation Physics and Medical Imaging

Advances in medical imaging technologies are continually developing. New imaging modalities have been incorporated, and a number of emerging techniques are presently being used to supplement or replace existing ones. Increased functionality is also seen in existing technologies, with artificial intelligence (AI) integrated and machine learning (ML) applied in various ways to enhance image interpretation. The potential for improved diagnostic accuracy, targeted treatment, earlier disease detection, and minimally-invasive therapy have improved significantly. Enhanced modalities, novel imaging agents, and therapeutic approaches have incorporated nanoparticles and other agents at the molecular level. In the future, the development of novel imaging agents will rely on a more sophisticated understanding of health and disease at the cellular and sub-cellular levels. With advances in material science, genetic engineering, and chemical conjugation techniques, the ability to precisely manipulate atoms and molecules has blossomed. This has led to the development of a whole new range of imaging agents with high molecular specificity and therapeutic efficiency [28]. Implementing innovative printing technology is also beginning exciting new possibilities for the development of 3-D imaging devices with high resolution and high signal-to-noise ratio. Moreover, software-based approaches using newly developed algorithms and AI applications for integration and automated

3-D processing of data from many highly resolved imaging sources will allow unparalleled insight into the complexities of the brain and the structural alterations that occur in neurological diseases. This has broad implications for the design and control of therapeutic strategies, with a more personalised therapeutic approach likely to be developed in the future [29]. The use of radiation physics and medical imaging is a truly cross-disciplinary approach, in which advances in one field may drive innovations in the other field. For the new or emerging medical imaging and therapeutic approaches become available, radiation physicists are pushing the field forward to reveal new technologies and treatment methods. Additionally, in order to improve patient care and drive technical innovations, collaborative work between radiologists, radiation scientists and other medical professionals is essential. This may lead to the development of practical imaging systems that take care of both legal aspects and patient health in the application of new medical imaging systems, or to enable that diagnostic or therapeutic systems designed to take advantage of cutting-edge technology to move beyond the prototype stage and become fully actionable. As well as providing improvements in device design from a professional medical perspective, this collaborative work also gives rise to more precise imaging algorithms and better and more accurate in vivo image interpretation, which reduces misdiagnosis. Given the significant investments usually required for new medical technologies, thorough collaboration across disciplines, as well as detailed financial planning based on previous advances and market conditions, is fundamental. By promoting stronger collaboration between researchers, hospitals and private industry on such new medical technologies and sharing openly methodology and hardware, the wider advantages of emerging diagnostic modalities and treatments can be shared.

6. Conclusion

Applying radiation physics in the field of medical imaging and treatment can have profound implications across the healthcare setting, due to the increased prevalence of radiation involved modalities and myriad of conditions. Thus, it is essential to have an understanding about radiation principles and practice in the clinical setting and towards the promoting of patient safety and best patient care. Various modalities and their clinical appropriateness and effectiveness will also be discussed, as well as a brief reflection upon the outcomes from a discipline comparison task completed with a nursing student.

One of the many tests and procedures which may be ordered by a clinician for the purposes of diagnosing an injury or condition is medical imaging. There are a variety of different imaging modalities which can be used, these include: radiography; CT; fluoroscopy; mammography; interventional radiology; bone mineral densitometry; MRI; ultrasound. At a logical level, both CT and MRI are able to provide cross-sectional images of the human body to diagnose a myriad of conditions without having to resort to invasive and possibly risky procedures, but there are major differences between the two. Currently, MRI is contraindicated during pregnancy, and in the presence of any form of metal within the body, such as a pacemaker or cochlear implant. Similarly, CT is contraindicated in pregnant patients as there is harm to the fetus if irradiated. Used in conjunction with the IV contrast for enhanced images of body tissues and structures, including the blood vessels, information on the circulatory system can be readily acquired and, hence, is the modality of choice for diagnosing many emergency traumas, e.g. internal bleeding, splenic rupture, and aneurysm.

However, the infamous dose received by patients from the CT scan is of concern, therefore, imaging must be used wisely and clinical justification is important. Using the ALARA principle, the overall dose can be reduced through optimization. A form of optimization with CT and in healthcare in general is justification. The expectations regarding the ongoing development of education, training and CPD for practitioners has the ultimate goal to address and resolve the problems identified during audit. One of the biggest challenges in healthcare is to get highly trained and savvy professionals who are aware of risk management good practice. Using assurance and regulation to address these challenges, safety standards have been implemented, which then is inspected. Professional and good practice is monitored closely and needed to be followed by each individual member of staff to ensure that the safety standards are met. All of these regulations make healthcare staff accountable for patient safety and they must ensure that no harm comes to the patients.

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